NASA's Fuel-Cell Program

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The goal of NASA's fuel-cell program is to obtain lightweight, dependable power sources to supply a variety of needs. These may include, for example, communication; command and control; guidance; radar; image acquisition, processing, and transmission; data handling and storage; life support; experiments on environments and planetary surfaces; and motive power for surface-exploration vehicles.

Among the major factors to be considered in the design of space-type fuel cells are (1) the need for very high reliability, because chances for repair are extremely limited even on manned missions; (2) high energy and power densities, because it costs between \$1,000 and \$5,000 to put a pound of substance into space, and our lift capabilities are limited while power requirements keep increasing; (3) the space environment, where gravity is absent or, on the surface of planets, varies from that on earth; where radiation and meteoroids present hazards; where temperatures can fluctuate widely; and where there is no atmosphere to provide oxygen and act as a heat sink.

As this is being written, work is in progress on the low-temperature fuel cell, with an ion-exchange membrane as electrolyte, which will power the Gemini spacecraft and on the intermediate-temperature modified Bacon fuel cell for the Apollo vehicle. The former, estimated to cost \$10 million, and the latter (\$28 million) represent the first functional uses of fuel cells. At the time of this presentation, it will have been decided whether a fuel cell will also power the lunar excursion module of Apollo. These multi-million dollar programs for developing flight equipment far eclipse the much more moderate research and development program of NASA. The former are the responsibility of the Office of Manned Space Flight, the latter of the Office of Advanced Research and Technology (OART).

In fiscal year 1963, OART spent about \$1.25 million on fuel-cell projects ranging from "basic" research to prototype development. On this occasion, I can only select a few examples of our work to illustrate the range of problems it covers and to give you some of the reasons for undertaking these projects.

On a NASA grant, Professor Bockris and his co-workers at the University of Pennsylvania are studying the dynamic behavior of porous electrodes, potentials of zero charge, and differences between chemical and electrochemical catalysis, among other topics. As part of a grant for work on energy conversion in general, this group is also working on the fundamentals of bioelectrochemistry. We thus hope to acquire basic information that will be useful for all kinds of fuel-cell systems. I shall return to biochemical fuel cells later.

An interesting hybrid between conventional batteries and fuel cells is represented by an idea advanced by Bernard Gruber, who proposes to impregnate a dry tape with anodic and cathodic material, one on each side, and adding electrolyte just before running the tape through two current collectors. By operating in this manner, one can activate the ingredients immediately before use, thus making possible indefinite storage as well as combinations of normally incompatible materials. This work is well underway at Monsanto and promises to yield high-energy-density electrochemical power sources that may compete with both primary batteries and primary fuel cells. The need for storable reactants -- for emergency use or energy-depot purposes -- may also be met by development of fuel cells that have multi-chemical capability and might utilize residual or excess amounts of rocket propellants, such as UDMH and nitrogen tetroxide.

In devising space power systems, we must consider not only the power source but also the equipment that is to be run from it. As a crude rule of thumb, we may assume 25% of the output will be needed as alternating current, 25% as direct current, and the remainder as either AC or DC. Furthermore, various devices will be operated at different voltages. Thus, power "conditioning" is an important factor in considering the electrical system as a whole. Mechanical and/or electric pulsing of fuel cells -- now being studied on grant as well as contract -- may yield advantages of several kinds: Longer operating life, improved resistance to poisoning of catalysts, lower concentration polarization, and greater power output from the fuel-cell battery; and better circuit control and higher conversion efficiency from the over-all system may be obtained by quasi-AC operation. Needless to say, such benefits, particularly as concerns the fuel cell proper, might be even greater in ground applications where hydrocarbons or alcohols are used directly as anodic fuels.

Another task that should benefit both earth and space applications is research on high-performance, thin electrodes that promise drastic cuts in fuel-cell weight and volume. Over the last two years or so we have progressed from perhaps 150 lbs. per kilowatt to about 70 lbs., exclusive of fuel and fuel tankage; 30 to 40 lbs. per kilowatt for fuel cell plus auxiliaries now appears to be in sight.

Work under way at Allis-Chalmers is directed not only at obtaining a space-type, low-temperature, hydrogen-oxygen fuel cell, with an asbestos retainer for the electrolyte; it is also concerned with finding a simple and reliable method for removing heat and water with the least number of mechanical moving parts and minimum need for parasitic power. This goal should be attained by evaporating water through a capillary membrane adjacent to the electrodes, the cavity behind the membrane being evacuated to a pressure corresponding to that of the vapor pressure of the KOH electrolyte at its operating temperature of about 200°F. Operability of such an arrangement has been demonstrated, control is simple, and temperature is not a critical factor.

Primary fuel cells, i.e., those through which reactants are passed once only, are useful in space only for limited periods. That is because the product of power and duration (=energy) determines the amount of fuel and oxidant that must be carried aloft. For extended missions, therefore, other primary sources of energy must be used. In connection with solar and nuclear energy sources and conversion devices, fuel cells may be used for energy storage, as secondary power sources during periods of darkness (solar primary power), during emergencies, and during periods of peak-power demand. Among the several methods of possible regeneration of reactants from products, only electrolysis and thermal treatment have proven practical thus far. Even so, it is not yet clear whether regenerative fuel cells will be competitive with secondary batteries or other secondary conversion devices.

At present, we have two efforts under way on secondary or regenerative fuel cells. One concerns improvements for a low-temperature hydrogen-oxygen cell, with electrolytic decomposition of water. The other is a K^+ diffusion cell, in which potassium ions are transported through the electrolyte and form an amalgam at the mercury cathode. The amalgam is then decomposed, by heating, into its more or less pure components. Whereas the former device appears particularly suitable for use in connection with solar energy, the latter could receive its primary energy from either solar or nuclear heat.

Biochemical fuel cells captured the public imagination some time ago. Meanwhile, further exploration of this 50-year-old concept has indicated rather severe limitations of power density and energy density for such devices. Nevertheless, they are likely to find specialty uses, even if these limitations cannot be overcome. One such possibility is to consider biocells as energy-saving waste disposals for extended space flights, during which human waste must be reprocessed for attaining a closed or nearly closed ecology. In addition to the grant mentioned earlier, NASA is supporting a threefold attack on this problem by sponsoring basic, applied, and developmental studies, aimed at finding materials and conditions conducive to degradation of human waste. Since the power consumed in such a device will undoubtedly exceed the theoretical -- let alone the realizable -- power output, this use of bioelectrochemistry is obviously not aimed at power production. If feasible, however, it may prove to require less net energy input than any other approach to waste reutilization. Similarly, biocells might profitably be considered as possible means for solving problems of water pollution, the power produced being a welcome byproduct.

What do we expect from space-type fuel cells? Our immediate, prime considerations are for high power density and reliability. The Gemini and Apollo fuel cells, for example, will have perhaps 1/6 to 1/10 the weight of the best available primary batteries that are capable of delivering the same total amount of energy. Furthermore, the product water will be used by the astronauts, an additional bonus not available from batteries.

Other requirements may become as important or even more so for different space applications. Longevity and ease of maintenance, for example, could well be the desiderata for fuel cells used at a lunar station or depot. Ease of packaging, storing, and converting chemicals to active species (say, hydrogen and oxygen) may determine what types of fuel cell will look most promising for propulsion on the moon or for powering space suits.

Apart from requiring a variety of fuel, each optimized for a particular task, we expect to see a much higher degree of sophistication in the mode of operation of fuel-cell systems. Increasing attention is already being directed toward optimization of controls and operating conditions. Each system must be optimized in such a way as to take advantage of the leeway permitted by its size, components, and operating variables.

Fuel cells will have to become truly integrated into the systems of which they will be parts. I already mentioned biochemical fuel cells as being primary chemical reactors, and the Gemini and Apollo fuel cells as being sources of potable water. Not only byproduct chemicals, but also byproduct heat could be useful in some cases. Once we have reliable information about the composition of the lunar surface, we may need to develop fuel cells particularly suited for lunar purposes and independent of supplies from earth.

This necessarily incomplete discussion of NASA's fuel-cell program will give you a feeling for the difficulties we face and the methods we use in attempting to overcome them. Virtually all of the information thus obtained should be equally as useful for earthbound as for space-type fuel cells. Thus, we hope not only to solve a part of the space power problem, but also to contribute directly to the advancement of fuel-cell technology that will benefit our economy. We are very much interested in your comments on our program and welcome your ideas and suggestions for fulfilling our task, which is to provide NASA with reliable, optimized fuel-cell power that will be applicable to many different jobs under a great variety of space and planetary conditions.